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A Critical Literature Review on Study of Critical Chain Scheduling in Construction Projects

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Abstract - *Every successful construction project has to be completed within the budgeted cost and the scheduled time. Constraints affect the project success. Therefore, proper management required to reduce the constraints. One of the traditional methods used worldwide is Critical Path Method (CPM) which leads to ineffective scheduling. In CPM, the task estimates are based on guesswork which leads to increase in the project completion duration. Also, the availability of resources is not considered by the scheduler to develop optimal schedules. The shortcomings of CPM are overcome by, a new project management method called "Critical Chain Project Management" (CCPM) was developed in 1990 by Dr. Eliyahu M. Goldratt after which various additions are added to his research. CCPM is based on the philosophy of "Theory of Constraints" (TOC) which believes that every system has a constraint & without eliminating this constraint the system cannot progress. The developing countries like India mostly face the problems of project delays so CCPM can be applied to save the projects from time and cost overruns. The aim of the paper is to describe the current status of research on CCPM and exploring opportunities to apply CCPM to construction projects and to compute buffer size by some methods. A scope of future study of detailed CCPM model can be developed based on TOC, and the developed model can be applied to on-going projects and future projects in India.*

Keywords: *CCPM, Theory of Constraints, CPM, Scheduling, TOC, Critical Chain*

I. INTRODUCTION

Critical Chain Project Management was developed and published by Dr E.M. Goldratt in year 1997.The book written by him in it describes that Critical Chain is a new commence for project management. Theory of Constraints is a tool for managing repeated network of outcome which is based on the principle that each and every organization has limitations, and organizations performance can be improved by increasing the performance of resource constraints. CCPM is an addition of TOC designed especially for project management. Critical Chain Project Management is described as an another solution to the long established method for planning and controlling of the project.

Critical Chain Project Management promoter states that it is a totally new method in a revolutionary way that leads to performance of the higher-ranking to reduce on-time delivery and to increase the capability to encounter budgets and schedule of a project. The main backbone of CCPM is to remove delay in uncertainty, delay in overestimated duration and dissipated delay of internal buffers. In Critical Chain scheduling duration of project do neither change, if all the safety margins of activity are removed because of project buffer. Buffering of projects saves the completion time of the project on CC path, at the same time feed buffers saves the critical chain from merging the path. Buffer management further enhances the decision making ability for controlling the project. Generally using CCPM emphasizes the schedule of project, performance scope and cost of the project.

II. LITERATURE REVIEW

Larry Leach P et al. (1997) critical chain project management improves the project performance and explained critical chain project management which provides a important step in the continuous improvement to the project organization for managing projects. Critical chain is dissimilar from the critical path which considers resource dependencies. By CCPM the project plan becomes better by making sure that it is possible and protected from sensible prevalent cause limits. It is done by combining uncertainty with buffers at the finish of the activity path. The project buffer protects the overall project completion on the critical chain path and feeding buffer protects the critical chain from path merging. Buffer management enhances measurement and decision making for project control. (27)

Graham K Rand et al. (2000) the paper has given an introduction to the development of the 'theory of constraints'. It explored the relationship of CCPM and other traditional methods like CCPM through the study of novel "Critical Chain". The traditional methods like CPM/ PERT do not consider the human behavior while constructing the project network. Thus, CCPM can be highly beneficial for the senior management level. The paper addressed, that project managers may avoid the use of CCPM approach as against CPM/PERT because it reduces the activity duration. (1)

H Steyn et al. (2002) the paper explained the reasons for reducing the project duration. The author has mentioned various reasons for reducing the project duration. First reason being, human behavior to provide considerable provisions for contingencies during project planning which further leads to overestimation. Secondly, multitasking by the worker leads to the negative effect on the project which should be avoided. Thirdly, CCPM provides the contingency reserves to whole of the project rather than to individual activity due to which project duration is affected. (2)

Francosis Retief et al. (2002) provided a brief review of the principles of critical chain scheduling in project management. Author states that the project performance can be better by scheduling project using CCPM. The improving project performance can be attained by modification of team behavior to reduce bad work habits and by using combine safety in the form of the buffers, and that protects the project finishing date. The paper also points the different ways due to which hold advance tasks that contains safety and people move forward to extravagantly for the available safety. The essential changes in CCPM as compared to CPM practices were mentioned which were reduction of activity times to 50%, the process of developing critical chain exploiting activity and resource logic, provision of the Various buffers to protect the critical chain from delays etc. All such essentials in CCPM lead to faster completion of a project and provide an effective project management tool to the executive's needs and organizations should be very careful in adapting CCPM techniques. The paper also points the various challenges which an organization might face in adopting a CC approach. (19)

Tzvi Raz et al. (2003) reviewed the key elements of CCPM like duration estimates, buffer design assessments, progress measurement, task finishing notification and priority setting time. Authors have done a detailed analysis of CCPM by using the information available in literature and practically. The point added includes duration estimation practices, project network diagram, the firmness of the critical chain, various resource effectiveness of the product under multi-tasking process and operational environment. The CCPM takes addresses the large project management concept and the costs that are associated with it that however CCPM states number of valuable concepts, the complete solution is not provided to project management. (25)

Izac Cohen et al. (2004) examines the control process of CC and few alternatives and demonstrates about CC that is not sufficient to block projects from running late, such possibilities may give better performance. The author examined control process of a multi-project environment, which was similar to organizations in the airplane industry and demonstrates that buffer size may not be sufficient to complete the schedule according to plan; different control methodologies are to be used such as QSC, ConPIP, and MinSLK to get same and better performance. More research is to be done for developing better scheduling and control process for multi-project environments. (18)

Lawrence P. Leach et al. (2005) the author takes reference from Goldratt 'The Haystack syndrome and quotes 'Measures drive actions that move you towards the goal'. It means that one must measure his performance which can help to judge the impact of the decisions to accomplish the ultimate goal. The paper suggests various action levels which were used to a make decision regarding buffer. They were categorized as no action assessment and plan and implement the plan. The author adapted a methodology in which Firstly the buffers were arranged according to the properties of the chain. Secondly, assessing the project progress and buffer consumption needs to be done on a regular basis. Thirdly, plans should be developed to accelerate the project progress if the pre-defined threshold of buffer consumption increases. If the second predefined threshold is exceeded, the developed plans should be implemented. Based on these thresholds, the author developed fever charts in which % feeding path complete is plotted against % buffer consumption. It was suggested that monitoring of fever charts should be done on a regular basis either daily or weekly. (30)

Thomas G Lechler et al. (2005) analyze the CC approach to manage projects. Their study was compared and analyzed CC & CPM on different levels to find the dissimilarity between the two approaches. Ronen & Starr (1990) analyzed, few other issues and the fundamental dissimilarity between Just In Time (JIT) and Optimized Production Technology (OPT) management on a scholarly& strategic level, their assessment of CO & CC was conducted on two level i.e. scholarly and strategic level. Further, paper identifies conceptual difference between CC and CP approach. It was concluded that CP is a well- established approach while CC completes the project faster but includes significant investment in the terms of training & framework investment costs is necessary to change to a CC perspective. (12)

Oya I Tukel et al. (2006) the authors have introduced two methods to determine feeding buffer sizes for preparing schedules using critical chain approach. The proposed techniques integrate project features into the formation. One of the technique integrates resource tightness while the different organization uses network complexity. Authors made an effort to integrate the CC concept into the resource-constraints project in their study which could be reviewed for further research into scheduling. The paper was tested & compared by two similar methods of buffer management i.e. the cut and paste method and the root square error method were used with no buffer as benchmark. The collation was done simulation study using the PDS. The authors introduced the Adaptive Buffer Sizing methods (APD) which were expected for generating buffer sizes and would improve the chances of a project completion time. (29)

Behzad Ashtiani et al. (2007) addresses the research issues for the use of lognormal distribution for task completion time and integrate the risk of tasks in order to determine the parameters of the distribution. A new method was proposed

to size the buffer based on Root Square Error Method (RSEM) approach. For simulation study, durations given in data set were considered while median time and then the scale parameter were determined for each activity. Lognormal distribution was used for tasks completion time and a new analysis was presented to determine the scale and shape parameters for each and every one activity. Further study was done to find out other statistics distribution for task completion time. All activities in the project distributions must satisfy the main features of completion time. Other extension of this study was to recognize new parameters that will be used to determine deviation activities. (22)

Kulkarni et al. (2009) noticed that project management was very difficult task and CC was necessarily required to complete the project on time and for improvement of services. behavior of human aspect was also studied and inscribe for success of any project. it was concluded that CCPM gives better and excellent solutions and it could be used with CPM at same time . MS Project was used for scheduling the construction project and it was found that time reduces by 20% to 30% which can be converted for saving cost and profit. (24)

Rob Newbold et al. (2010) the paper suggests that multitasking should be avoided to complete the project within stipulated time. If a same type of resource is to be used for more than one activity at certain point of time, such activities should be scheduled at different points of time. The paper gives an idea about the use of fever charts, buffer penetration, and consumption of buffer which represent the status of the activities on the fever charts. The fever chart was divided into three zones viz Red Zone, Yellow Zone and Green Zone. The paper has given definitions of some important terms related to CCPM such a project buffers, iteration risk, fever chart, critical chain, buffer consumption. (28)

Francisco Correia et al. (2011) identified that the calculation of the Critical Chain (CC) approach and Theory of Constraints (TOC) was adapted to Project Management as an important element for helping for the promotion of the development in a construction field. Author gives a detail discussion for both CPM and PERT method and added some discussion about the benefits and drawbacks of the CC regarding traditional approaches. (7)

Sarkar et al. (2012) presented that CCPM methodology was applied to private project construction. The research analysis was carried out using MS project software. Author gives conclusion that CCPM has actually provided a more effective method for project management. (16)

Ganesh P. Gaikwad et al. (2012) the paper gives a brief about the traditional project management techniques and gives an overview of the CCPM technique. The paper also suggests the advantages of using CCPM over the traditional methods. The various reasons for the project delays were the use of excessive activity duration estimates, little actual activity positive variation, project delay caused due to merging of activity paths, multi-tasking and loss of focus. The paper describes various theories on which CCPM is based viz. Theory of Constraints, Common Cause Variation and Statistical Laws Governing Common Cause Variation. With the help of this paper, the author has pointed out towards the undesired effect of the traditional methods of scheduling. (8)

Kaushik M et al. (2013) this research shows that selected parameters were responsible for CCPM to have not been implemented in the Indian construction context. Survey data was collected from various construction firms in India. The respondents involved managers and engineers who belonged to either the execution department or the planning department or the tendering department. A total of 29.4 % of the respondents were managers and the rest were engineers. The respondents were mostly from particular regions in India namely Andhra Pradesh, Goa, Tamil Nadu and Gujarat and the results have been generalized to India. This research was useful to the top management in the construction sector. This sector should realize the importance of concepts like six-sigma, 5S, CCPM etc. All these concepts are proven techniques and have worked wonders, in terms of productivity improvement, the safety of personnel at workplace i.e. fewer accidents, increase in profits etc., in whichever industry they have been applied. (20)

Guofeng Ma et al. (2014) presented Improved CCPM framework for construction projects. It addresses that two major challenges in Critical Chain based construction scheduling which includes buffer and multiple resource leveling. buffer simulates an important role in protecting successful schedule management. A case study of real project was used in the paper to check the CCPM framework. The Uncertainty Aware Method (UAM) outperformed the results. (10)

Siddesh K. Pai et al. (2014) used Critical Chain (CC) method to analyzed the management of projects. Some authors says CC can be an advanced method for managing the projects, since CC simply consist of well known ideas presented in another way. Author shows comparison in a systematic way for CC and CPM on various levels to identify the distinction between this two approach. Author gives conclusion about the philosophy of the CP and CC method which is peculiarly different resulting in a different mindset for the managers and various set of management practices.CC focuses to improve the performance of the system by making some specific policies from which many focuses on managing the resources for a multi-project environment that are not addressed by CP. Author also concludes that the implementation of CC is a complex process, much more ideas can be simply habituated by managers. (15)

Shurrab M et al. (2015) the main aim of this paper was to compare the traditional CPM against CCPM. It uses the two methods of buffer management namely SSQ method and CPM techniques to analyze the project capability related to cost

and duration. The networks are tested by two ways for the study. Firstly, the networks are developed without using mixed resources and after that with mixed resources. for achieving the research objectives, 120 conjunctions of unplanned generated project networks were calculated and assessed by the author by using the 2 methods i.e. Critical Path Method and Critical Chain Project Management. Results show that there has been a considerable reduction in cost and duration using SSQ method while C & PM method overestimates the duration but it also saves the cost. (26)

M.Ghaffari et al. (2015) the paper aims at reviewing the research on CCPM critically. This study covers 140journal & conference papers which have been reviewed to carry out the extensive research on CCPM. The papers have been categorized into 6 groups using "hierarchical coding method", based on the approach & contribution of these papers towards CCPM. The six categories as reviewed were introductory studies, critical studies, improving studies, empirical studies, case-reporting studies and exploiting studies. The introductory studies mainly addressed the introduction of CCPM, its principles and support the practice of CCPM against the other traditional methods. The Critical studies highlight the drawbacks of using CCPM and propose various means of overcoming them. Researches done on improving studies category aimed at improving the drawbacks addressed in the critical studies. In this task duration improvements, buffer management improvement and project monitoring improvements have been addressed upon. In empirical studies, researches have been carried out to investigate the performance of CCPM with the help of experiments and simulations like Monte Carlo Simulation which mainly show that CCPM performs better than the other traditional methods. Under case-reporting studies category, the author studied 20 case studies on CCPM and most of the papers reviewed have reported the benefits of CCPM viz. increase in productivity, efficient on-time delivery rate, reduction in multi-tasking, increase in throughput & increased work progress. Through exploiting studies, the application of Exploiting studies through TOC to other fields have been focused which include accounting firms, procurement management, supply chain management, software development firms etc. (11)

Hosein Iranmanesh et al. (2016) the paper contributes to effective buffer sizing. If the buffer was not sized to accommodate the uncertainty, it can lead to the loss of critical chain technique. The paper suggests Post density method (PDM) to take into account the uncertainty, post density factor, and dependence factor to decide the effective buffer size. Four performance indicators were used in the study to violate the times. Kolish-Hartman datasets were used in the simulation study. The solution of simulation specify that PDM evaluates the small size of buffer in environment where uncertainty is less and large size of a buffer which highly uncertain to the environment than available methods. According to the study, it was found that Post Density Method saves the time of the project and adjusts it with the principal goal of CC management. Decreasing Work In Progress can be used as a suitable technique for identifying the size of a buffer. (17)

Debasis Sarkar et al. (2016) shows the result of the potential benefit of CCPM methodology based on buffer strategies can produce an unprecedented level of optimization in resources, production throughput, with certainty in complex infrastructure projects like construction of elevated corridor for metro rail operations. The use of the case to test the proposed CCPM methodology shows the feasibility to apply it within the construction scheduling context in repetitive projects. As a scope of the future study, a detailed CCPM model can be developed based on TOC, and the developed model can be applied to on-going projects and future metro rail projects in India and abroad. Further, as the concept is generic, the same concept can be applied to other complex mega infrastructure projects. (9)

According to **Priya Bhagdewani et al. (2017)** this paper presents the logical foundation between approaches, and further discusses the possible relations between them. Based on a numeric example and on the assumptions, this paper argues that, despite searching optimizations in its origin, TOC currently presents few common points with LP. Based on experience & assumptions, one can list out the probable causes of delay &identify the root for the same. At the execution stage, the management should keep record of the work and should be aware of the limitations that they encounter initially. The management should fortify that resources like money, facilities, staff, and various types of equipments are assigned to decrease the limitations from the constraints confronted. After studying the basic concept of TOC, the application of it can be done by simple Linear programming method. The paper describes the theoretical and practical knowledge about Theory of constraints. At that time , a goal was to identify the way to Incorporate TOC by identifying the scope, cost estimation, project management, proper planning, and scheduling. (33)

Manisha N. Ghotnekar et al. (2017) in this paper the representation of comparative survey of constraint's theory and critical chain project management's application, which is well established according to the critical path method for the program planned and scheduled in MS project software for the construction of the project with commercial essence. The status of the projects in terms of data, values, and visuals was obtained by using MS project software and the corrective measures on the constraints occurred in the project schedule are solved by the application of TOC, Critical Chain Management, and management of buffer to ensure the success of projects. (34)

Mona P. Prajapati et al. (2017) the aim of the paper was to explore the opportunities to apply CCPM by means of a literature review to minimize uncertainty and variation in project activity duration. It also describes theories behind CCPM network and procedure of preparing CCPM network. From this paper, it was said that instead of using task-based scheduling it will be more fruitful to apply resource-based approach for the project schedule. A brief review of CCPM

was presented from where it was started and today many countries are taking its advantage. The country, which strictly implemented the approach to get better results, is the Japanese who use Critical Chain project management (CCPM), to control the vast majority of their infrastructure projects. Local governments prefer contractors who use Critical Chain to manage and control the vast majority of their infrastructure projects. (35)
Based on the literatures studied, the following figure has been shown, describing the studied papers published till the year stated and indicating the key findings till this year.

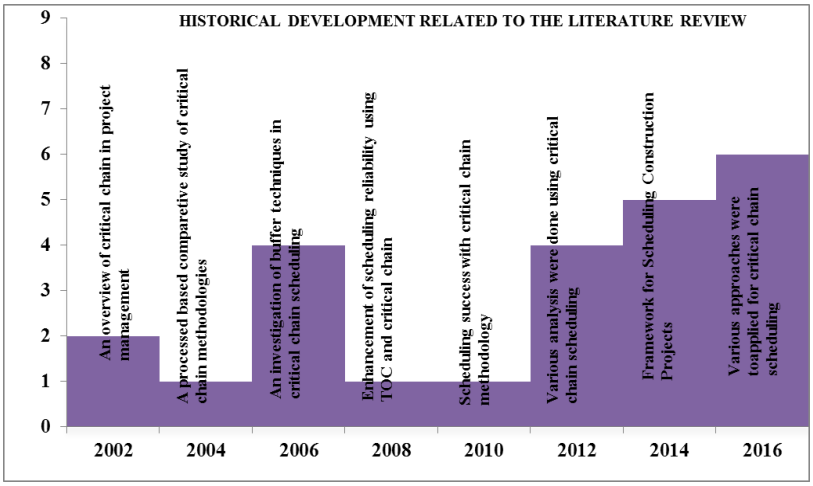

Fig. 1: Historical development related to literature review

IV. CONCLUSION

The performance of the project does not matter in managing the constraints of the planned schedule and it is purpose of particular skills and efficiency of leaders which includes fluent customer requirements and understanding their future needs and obtaining cooperation all over the organization. Critical Chain Project Management is based on assumption that uncertainty is the major factor in anyone duration of activity that affects the capability to finish the project on time. However there subsist many more admissible misconception practices which affects the expectations of schedule such as pressure from outside, internal conflicts and false estimates to succeed the project which must be inscribed.
the following factors have been identified and classified into different groups as follows:

1. For pre-existing conditions, factors identified from previous work are as: size of organization, use of scheduling techniques, project focus, project attributes, project management practices.
2. For established goals, factors identified from previous work are as: project completion percentage, change of scope, increase throughput, cost increment is less, financial benefits ,quality, manage resources, on-time delivery.
3. For implementing CCPM factors, factors identified from previous work are as: rescheduling as exception, clear scope, drum buffer, priority task list, contractor integration, duration estimates, resource buffer, baseline of critical chain.
4. For change management factors, factors identified from previous work are as: involvement of stakeholder, adequate training, incremental measurements, vision, role changes, software functionality, project planned, performance measurement.
5. For CCPM specific factors, factors identified from previous work are as: Desire for standard, task duration, focused work, management interruption, delayed status.

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ANNEXURE

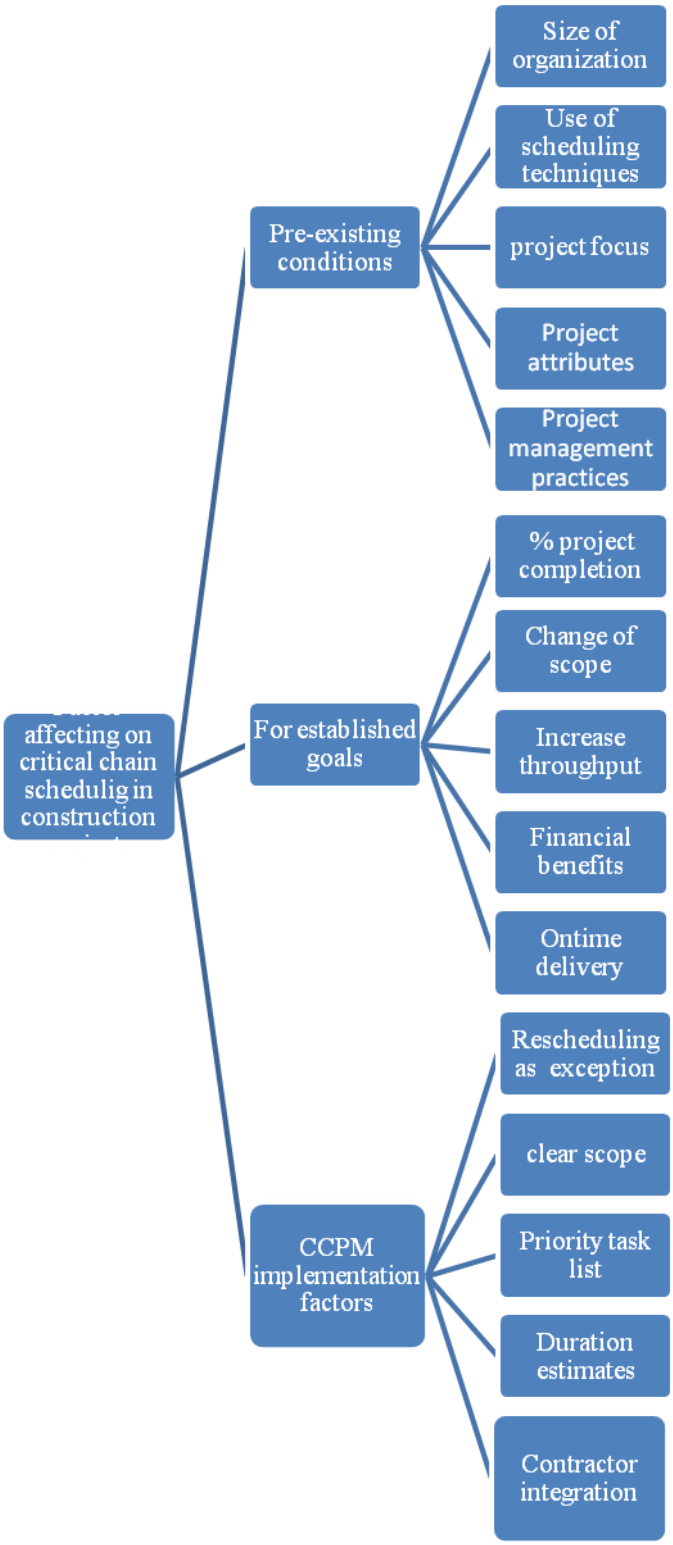

Figure 1 : Integrated framework for assessing factors affecting Critical Chain scheduling in construction projects

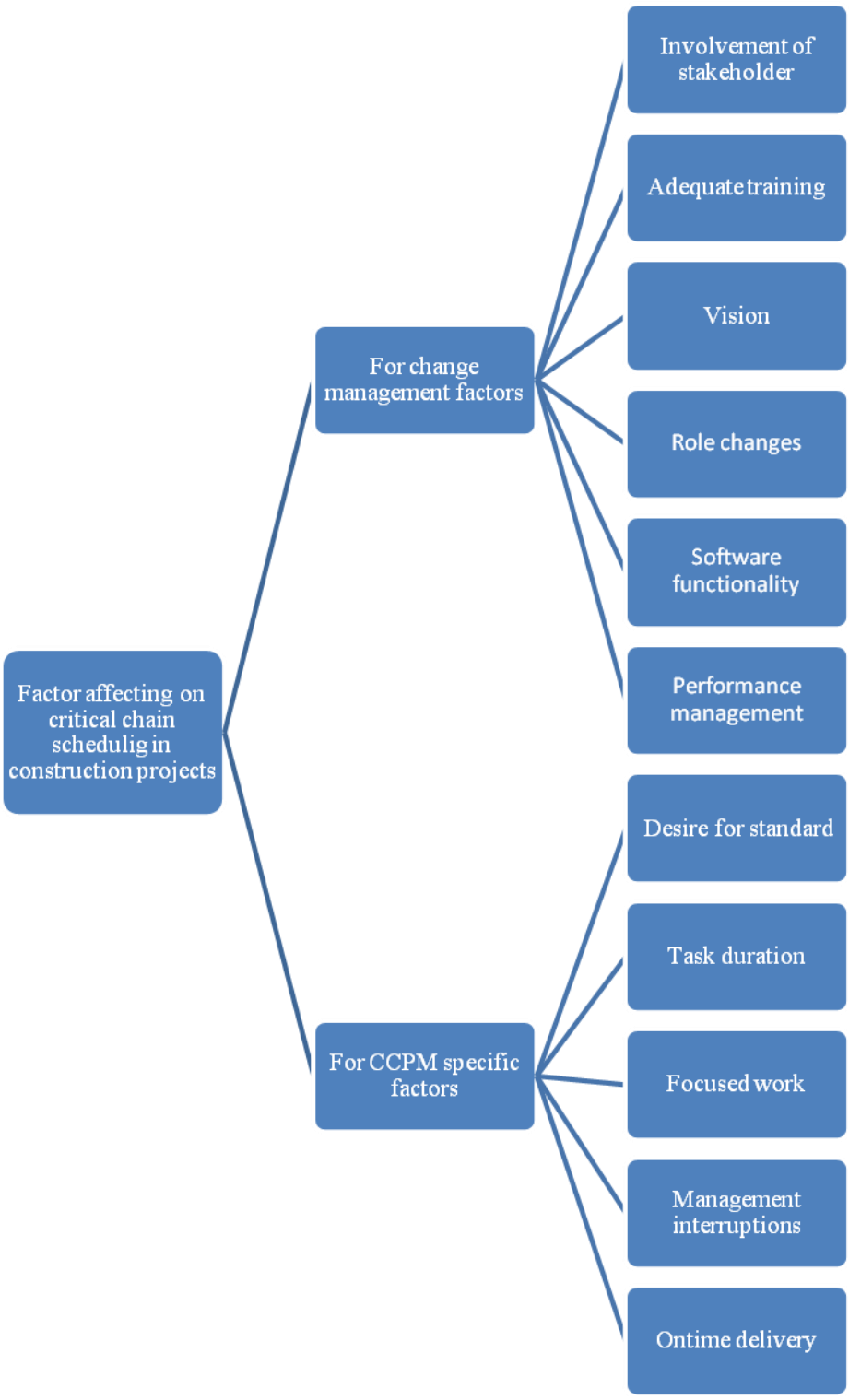

Figure 1 (a): Integrated framework for assessing factors affecting Critical Chain scheduling in construction projects

